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STUDY OF STABILITY ANALYSIS OF CONTROL SYSTEM FOR DEVICES OF MOBILE TELECOMMUNICATIONS

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ABSTRACT

In this article we propose the design method based on the root locus for the study of absolute stability to assess the efficiency of devices of digital radio receiving systems that are closed control system.

We consider the noise immunity of the coherent navigation GPS receiver in a broadband interference of the type of code-phase-shift signal and chirp signal for CDMA communication systems and radar systems.

The noise immunity is evaluated by simulation of operation of the GPS receiver and on the base of models of optimum filtering theory.

Index Terms - digital radio receiving systems, absolute stability, noise immunity, GPS receiver.

1. INTRODUCTION

The design of digital radio receiving systems (DRRS) of persistent signals, receiving signals from moving objects, is considered. First, we analyzed of stability of the system. Input DRRS signal comes from the antenna output or amplifier of a high or intermediate frequency with different modulation formats. The system produces not only filtering and demodulation of analog narrow-band signal, but also the primary digital processing of extracted information through the ADC [1]. DRRS in the GPS gives the results of evaluations of current navigation parameters; synchronization and demodulation of carrying oscillation; synchronization and demodulation of subcarriers and modulating them ranged harmonic oscillations; synchronization and demodulation of binary characters; measuring of the signal parameters in order to obtain tracking data and evaluate the receiving quality. Systems must have high noise immunity to work in conditions of intentional interference by suppression of narrowband station interference at minimal spectrum distortion of the receiving signal. Engineering calculation of digital closed systems of synchronization can be performed using quasicontinuous model consisting of the discriminator block and the linear part block with transfer function, which is the product of the transfer functions of a digital filter and digital synthesizer. The discriminator model consists of a differential part, a nonlinear part with a discriminatory characteristic, and the summation part, which receives the white noise and represents a circuit with constant parameters. We use the general theory of root trajectories in control of continuous systems [2].

The noise immunity of navigation receiver of complex signal is investigated. Impact on GPS navigation receiver interference of various types on the C/A-code are investigated [3] and recommendations for acceptable interference impacts of international companies ARINC, RTCA, EUROCAE are proposed. Investigations of the impact of interference on the high accuracy channel using range-measuring P-code are necessary. Modern communication system of CDMA standard and radar systems use for sending and retrieving of information broadband signals with different types of code modulation, thus estimation of the noise immunity by analytical methods is problematic. To solve the problem of evaluation of the noise immunity of the GPS receiver, we use the method of modeling of electronic environment, of structures of the coherent phase-shifted range-measuring code receiver and navigation computer of consumer equipment [4].

2. METHODS FOR STABILITY ANALYSIS OF CONTROL SYSTEMS

For the stability analysis of nonlinear digital systems the method described in [3] was applied. We designed the mathematical models of discrete systems in the form of analytical equations of the functional root locus, which consider the form of modulation, nonlinearities of elements, ADC, using CPU, DAC, the delay and distributed parameters. Geometric criteria for evaluation of the absolute stability of systems are developed. A computer-oriented method of stability analysis systems of regulation for radio receivers of mobile communications is proposed.

Frequency criteria [5,6] for the study of nonlinear pulse systems, taking into account the characteristics of the nonlinearities were the basis for the formation of mathematical models for the geometric study of absolute stability equilibrium of DRRS on z-plane.

In [7-9] an algorithm building a mathematical model to study the dynamics of some class DRRS, consisting of a nonlinear element (NE), whose characteristic φ(σ) belongs to the sector (0, *k*) and to satisfy certain conditions (CNE), then a stable linear discrete part (LDP) and an element of account of the time delay (DE) is presented.

Applying z-transformation and its modifications we can write the transfer function LDP system DRRS, first as a product of rational functions LDP and TD and then in the complex form:

$$G^*\left(\delta^*,\omega^*\right)=G_{\mathrm{o}}^*\left(\delta^*,\omega^*\right)\cdot G_{\mathrm{d}}^*\left(\delta^*,\omega^*\right)=$$
$$=\frac{\left(P^*+\mathrm{j}R^*\right)}{\left(E^*+\mathrm{j}F^*\right)}\cdot\frac{\left(A^*+\mathrm{j}B^*\right)}{\left(C^*+\mathrm{j}D^*\right)},$$

where the polynomial functions of two independent variables δ^* and ω^*, P^*, i.e. $P^*\left(\delta^*,\omega^*\right)$, E^*, A^*, C^* - even degree, i.e. real parts, respectively, the following polynomials $P_0\left(z,\varepsilon\right)$, $Q_0\left(z\right)$, $P_{\mathrm{d}}\left(z,\varepsilon\right)$ and $Q_{\mathrm{d}}\left(z\right)$ and R^*, F^*, B^*, and D^* - odd powers determined by the following generalized formulas [9].

3. MATEMATICAL MODEL OF DIGITAL SYSTEMS FOR THE STUDY OF STABILITY PROJECTED DEVICES

To improve the quality indicators of processes in the system by restricting the class of nonlinear characteristics of the function $\varphi\left(\sigma\right)$ adds additional constraints [5].

Let us consider a study of the stability DRRS with delay on the characteristic of NE:

$$\varphi\left(0\right)=0;\quad r<\varphi\left(\sigma\right)/\sigma<k_1\ ,$$

which impose additional

$$\sup \mathrm{d}\,\varphi\left(\sigma\right)/\,\mathrm{d}\,\sigma=k_1'\ .$$

In [7] we have presented a mathematical model as a basic analytical equation of the functional root hodograph to study the absolute stability of the equilibrium DRRS:

$$\begin{aligned}&\left(k_1-r\right)\Big[\left(E^*P^*+F^*R^*\right)\left(A^*C^*+B^*D^*\right)-\\&-\left(E^*R^*-F^*P^*\right)\left(B^*C^*-A^*D^*\right)+\\&+r\left(P^{*2}+R^{*2}\right)\left(A^{*2}+B^{*2}\right)\Big]-\left(k_1-r\right)q\times\\&\times\Big\{\left(1-\delta^*\right)\Big[\left(E^*P^*+F^*R^*\right)\left(A^*C^*+B^*D^*\right)-\\&-\left(E^*R^*-F^*P^*\right)\left(B^*C^*-A^*D^*\right)+\\&+r\left(P^{*2}+R^{*2}\right)\left(A^{*2}+B^{*2}\right)\Big]+\\&+r^2\left(P^{*2}+R^{*2}\right)\left(A^{*2}+B^{*2}\right)+\\&+\left(E^{*2}+F^{*2}\right)\left(C^{*2}+D^{*2}\right)=0.\end{aligned}$$

A mathematical model for the geometric interpretation in the plane of absolute stability of the equilibrium DRRS design extends to a broad class of nonlinear characteristics, resulting in engineering calculations for obtaining narrow parametric regions of stability.

4. GEOMETRIC CRITERIA FOR EVALUATION OF STABILITY

We define the geometric condition of absolute stability DRRS with delay: in order to make the equilibrium position in DRRS with time delay and a stable LDP perfectly stable in the sector (0, *k*), it is enough to put root locus entirely inside of the circle of unit radius with the center at the origin of coordinates of plane *z*.

5. RESULTS AND DISCUSSION

5.1. Model of the received satellite signals the GPS

Signal received from *i-th* navigation satellite by consumer equipment can be represented as

$$b_i(t-\tau_i)=A_p\left[P_i(t-\tau_i)\right]\cos\left[2\pi(f+f_{dop\ i})(t-\tau_i)+\varphi_i'\right]+$$
$$+J(t)+\gamma(t),$$

where A_p, φ'_i are the amplitude and initial phase of the signal at the receiving point; $P_i(t)$ is the Sector of precise range-measuring code; $f_{dop\ i}$, τ_i - Doppler frequency shift and propagation delay of carrying oscillation from *i-th* navigation satellite; $\gamma(t)$ is white Gaussian noise with zero mathematical expectation and dispersion $0.5N_0\delta(t_2\text{-}t_1)$; N_0 is one-sided spectral density of white noise; J(t) is broadband interference. Measured parameters of radio signals, which are used by navigation computer, are τ_i and $f_{dop\ i}$. The block diagram model of the optimum receiver of phase-shift signal uses interdependent tracking phase locked loop (PLL) and delay lock loop (DLL).

5.2. Algorithm for solving the navigation problem

The algorithm consists of evaluation of navigation parameters and calculation of the state vector of navigation satellite (NS) based on ephemeris. Evaluation of navigational parameters is calculated by the least-squares method (LSM), which uses signals from all satellites in the visibility zone [1]. Define the consumer vector in fixed geocentric coordinate system as $X=\left|x\,y\,z\,D\right|^T$.

The estimation algorithm can be written as [1]

$$\hat{X}=\hat{X}_0+(H^T(\hat{X}_0)H(\hat{X}_0))^{-1}H^T(\hat{X}_0)(\hat{D}_{mes}-D_{pc}(\hat{X}_0)),$$

where $\hat{X}_0$ is the initial estimation of consumer vector; $\hat{D}_{mes}$ - values of the pseudoranges up to the NS, measured at the stage of primary processing; $D_{pc}(\hat{X}_0)$ - calculated distance to the NS; the matrix $H(\hat{X}_0)$ is determined at the $\hat{X}_0$ point of estimated values of consumer coordinates. Implementation of the algorithm requires the information about the coordinates of satellites at the time of the signal emission. Such information can be obtained by calculating the state vector of the NS on the basis of ephemeris information.

The algorithm is based on the Keppler model of the unperturbed motion of the satellites, using the WGS-84 constants.

5.3. Algorithm for solving the navigation problem

To evaluate the noise immunity of navigation computer (NC), which implements algorithms of secondary information processing, the following structure (Fig. 1) was used.

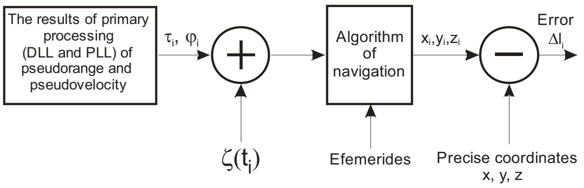

Figure 1 Block diagram of simulation of noise immunity algorithm of secondary information processing

The input received the results of primary treatment obtained by of delay and Doppler frequency measurement tracking systems (DLL and PLL, respectively for τ_i and φ_i). The file of the measurements is presented in the RINEX format. It contains the ephemeris for all of radio-visible satellites, and the results of measurement of pseudo-range and pseudo-velocity of signals on satellite at two frequencies L1 and L2. File contains the measurements information for approximately 24 hours. Further, to the results of measurements containing in the original RINEX file, the additive random process $\zeta(t)$ with the distribution law, controllable by the developed software, is added. Then the mixture "signal + noise" is fed to the input of the algorithm of the secondary processing, which also served ephemeris. The calculation results of secondary processing algorithm are the coordinates of the object navigation x_i, y_i, z_i. Then the coordinates calculated in this way are compared with the true and calculated error vector is estimated. In simulation was used a normal distribution law of continuous random variable $\zeta(t)$ with expectation parameters $\langle \tau_0 - \tau^* \rangle$ and dispersion σ_τ^{2*}, obtained as results of simulation of circuits of range signals processing. Since the $\langle \tau_0 - \tau^* \rangle$ and σ_τ^{2*} parameters of measurements of pseudorange DLL are associated with the signal to noise ratio, according to the results of simulation algorithm of secondary processing, we obtain the dependence of the root-mean-square deviation (RMS) of the error vector of navigation computer on the signal-to-noise ratio q at the input of signal processing circuit of range signals. The simulation was performed in two stages. In the first phase were obtained depending on error measuring the delay and Doppler frequency shift of the signal to noise ratio at the inlet for different types of interference. At the second phase the dependence of the navigational error calculator from the errors of the primary gauges (DLL and PLL) was investigated.

The simulation results are presented in Fig. 2.

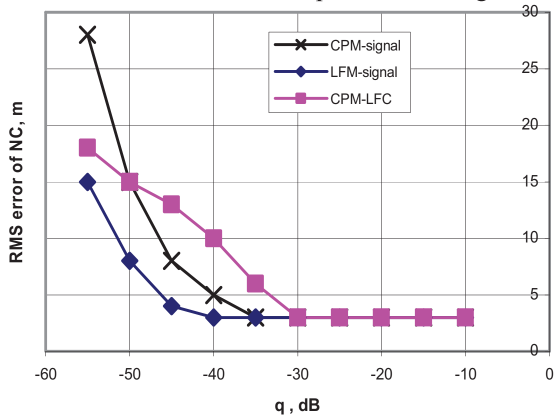

Figure 2 Dependence of the RMS errors of navigation computer on the signal-to-noise at intermediate frequency of f_0=130MHz, sampling frequency of f_d=10 f_0 MHz; clock frequency sequence of F_d=10.23 MHz

The dependence obtained makes it possible to characterize the influence of power of broadband noise and give recommendations to the choice of signal-to-noise ratio, at which the RMS of navigational computer does not exceed the required threshold.

For example, for the operation of navigation computer with an error less than 5 m, under the influence of disturbance type CPM-signal with a linear frequency change, the required signal to noise ratio should be $q \approx$-33 dB. For the interference of CPM-signal type, the limiting power ratio will be -40 dB, and for LFM signal $q \approx$-46 dB.

5.4. Modeling noise immunity navigation receiver.

Consumer equipment of satellite navigation system operates in a complex noise conditions of both artificial and natural origin. Interference located in a band of navigational signals influences on signal processing circuits and the characteristics of modes of operation. At the stage of the structure design of the receiver one should take into account noise immunity of navigation signal processing systems. One of the methods of estimation of noise immunity is the SNR in the tracking correlator, which can be obtained by dynamic simulation of the correlator operation in the selected signal and noise conditions. For LFM interference the frequency deviation is 100 kHz, the repetition period is 0.1 s.

As a pseudo-random sequence of interference signal the D-code with the number of counts equal to 4096 and the clock frequency of 0.45 MHz is selected.

The parameters of frequency changes are: the frequency deviation is 200 kHz, the repetition period is 0.1 s.

At the Fig.3 the simulated and experimentally obtained dependences of SNR C/N_{EQ} [dBHz] on the amplitude gain coefficient of interference signals are presented.

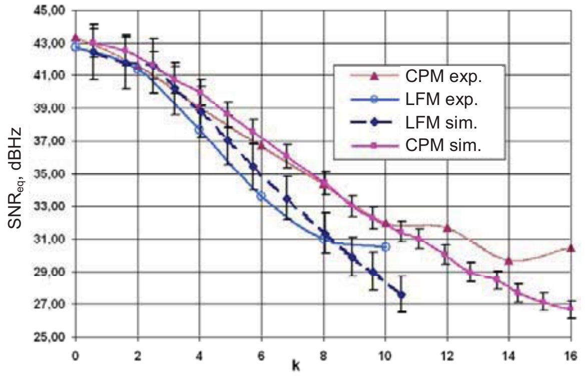

Figure 3 The dependence of C/N_{EQ} on the noise amplification coefficient

In the experiment the navigational receiver TRIMBLE Lassen SK II was used.

Fig.3 illustrates that the error between the experimental and simulated results did not exceed 7%, which gives an indication of acceptable accuracy of computer models.

6. CONCLUSIONS

The mathematical model for analysis of the absolute stability of nonlinear DRRS, taking into account the nonlinearity, is proposed and a geometric condition for absolute stability of the equilibrium of DRRS in the form of the trajectories of the root hodograph on a circle of radius Z - plane is given. Upon studying the trajectory of a mathematical model the design parameters are changing and the mobile communications unit is designed.

Noise immunity is evaluated by simulation of operation of GPS receiver and on the models of optimum filtering theory.

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